Hurricane Andrew's Effects on Marine Resources
Author(s): James T. Tilmant, Richard W. Curry, Ronald Jones, Alina Szmant, Joseph C. Zieman, Mark Flora, Michael B. Robblee, Dewitt Smith, R. W. Snow and Harold Wanless
Source: *BioScience*, Vol. 44, No. 4, Hurricane Andrew's Sweep through Natural Ecosystems (Apr., 1994), pp. 230-237
Published by: Oxford University Press on behalf of the American Institute of Biological Sciences
Stable URL: http://www.jstor.org/stable/1312227
Accessed: 20-09-2017 17:07 UTC

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at http://about.jstor.org/terms

American Institute of Biological Sciences, Oxford University Press are collaborating with JSTOR to digitize, preserve and extend access to *BioScience*

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms

Hurricane Andrew's Effects on Marine Resources

The small underwater impact contrasts sharply with the destruction in mangrove and upland-forest communities

James T. Tilmant, Richard W. Curry, Ronald Jones, Alina Szmant, Joseph C. Zieman, Mark Flora, Michael B. Robblee, Dewitt Smith, R. W. Snow, and Harold Wanless

Hurricanes are a particularly destructive force to shallow-water marine environments. Throughout the tropical regions of the world, hurricanes have played a significant role in periodic ecological perturbation of coral reef communities. They may be a major factor promoting the coexistence of competing species in highly diverse tropical ecosystems such as rainforests and coral reefs (Connell 1978, Pearson 1981, Porter et al. 1981). Nearly every major hurricane crossing the Caribbean during the last century has resulted in reports of massive disturbance to large areas of coral reef, adjacent seagrass beds, and coastal mangrove habitat (Porter et al. 1981, Shinn 1972, Stoddard 1963, Tabb et al. 1962). When Hurricane Andrew passed over south Florida on the morning of 24 August 1992, we anticipated severe damage to the marine resources. In addition to the immediate damage, there was likely to be a delayed impact associated with storm-related pollution and increased nutrient loading.

James T. Tilmant is a chief scientist with the National Park Service, Glacier National Park, West Glacier, MT 59936. Richard W. Curry is the science coordinator at Biscayne National Park, Homestead, FL 33030. Ronald Jones is an associate professor and director of the southeast environmental research program at Florida International University, Miami, FL 33199. Alina Szmant is an associate professor of marine biology and fisheries in the Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, FL 33149. Harold Wanless is a professor of geology at the University of Miami, Miami, FL 33149. Joseph C. Zieman is a professor of environmental sciences at the University of Virginia, Charlottesville, VA 22903. Mark Flora is acting chief of the Planning and Evaluation Branch, National Park Service Water Resources Division, Denver, CO 80228. Michael B. Robblee is a marine research ecologist with the National Biological Survey stationed at Florida International University, Miami, FL 33199. Dewitt Smith is a program manager for natural resources inventory and monitoring and R. W. (Skip) Snow is a marine resource specialist at the South Florida Research Center, Everglades National Park, Homestead, FL 33030.

We must monitor whether the marine ecosystem can overcome the expected increases in turbidity, nutrient concentration, and sediment destabilization

Assessment procedure

The marine resources team focused on water quality, sediment movement, seagrass beds, hardbottom communities, coral reefs, mangrove forests, tropical fish, and marine wildlife populations as major ecological elements. Our approach included air, boat, and underwater (scuba) field surveys to map geographic boundaries and to document readily observable impacts. Wherever possible, we visited specific study sites where pre-storm resource information had been collected.

In addition, we conducted underwater surveys along east-west and north-south gradients across the entire pathway of the storm track to determine the geographical extent and nature of the impact. Underwater observations extended eastward to the outer edge of the main reef formations (approximately 25 m depth) and westward off the western coastal mangroves to a depth of approximately 7 m.

Resource conditions

Water quality. Hurricane Andrew had a significant impact on marine water quality. Turbidity, nutrient loading, and dissolved organic carbon all increased both inside and outside the areas of the storm's direct impact. Pollutants, in the form of oil spills and motorboat fuel, were particularly evident. During our assessment, several areas near shore retained high turbidity due to both suspended sediments and post-storm plankton blooms.

Biscayne National Park. On 25 and 26 August, immediately after the storm, dissolved oxygen levels in near-shore areas of Biscayne Bay were near zero due to high turbidity

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms

and the loss of primary productivity.[1] Schools of fish were frequently on the surface, and numerous lobsters were climbing the walls near the surface of a coastal discharge canal at Gables by the Sea. Large quantities of petroleum oil and motorboat fuel were floating on the surface of the bay near each of the major marinas. Sunken boats in the bay were releasing diesel and gasoline fuel. A flight over the area on 19 September revealed a continued heavy plume of fuel discharging into Biscayne Bay from the area of a collapsed boat dry-storage building at the Black Point Marina.

During our assessment, dissolved inorganic nitrogen and organic nutrient concentrations were higher than normal in Biscayne Bay. The bay was experiencing a phytoplankton bloom promoted by the recent influx of runoff and debris. If it persists for a long period, this bloom could seriously affect benthic macrophytes, especially seagrasses, and benthic filter feeders such as sponges.

Five coastal drainage canals discharge into Biscayne Bay between the northern boundary of Biscayne National Park (near Cutler Ridge) and the park headquarters (Figure 1). The South Dade Landfill and a Regional Wastewater Treatment Facility are adjacent to one of these canals (Black Creek), less than 1.5 km from the drainage canal's discharge point.

We sampled water in each of the canals on 16 September and again on 19 September. The Black Creek Canal was severely degraded. Very high concentrations of ammonium, total organic carbon, and elevated chlorophyll A and alkaline phosphatase levels were found in the vicinity of the South Dade Landfill. Preliminary measurements indicated that total coliform bacteria was significantly higher than the historical medians at most sites sampled. It is probable that sewage contamination affected the canal waters during and after the storm. However, we need further analysis of samples to verify these early results.

Nutrients and chlorophyll values within the offshore reef zone were within the normal range for this area. There was no indication of nutrient-enriched waters exiting the bay to the reef areas during our sampling period.

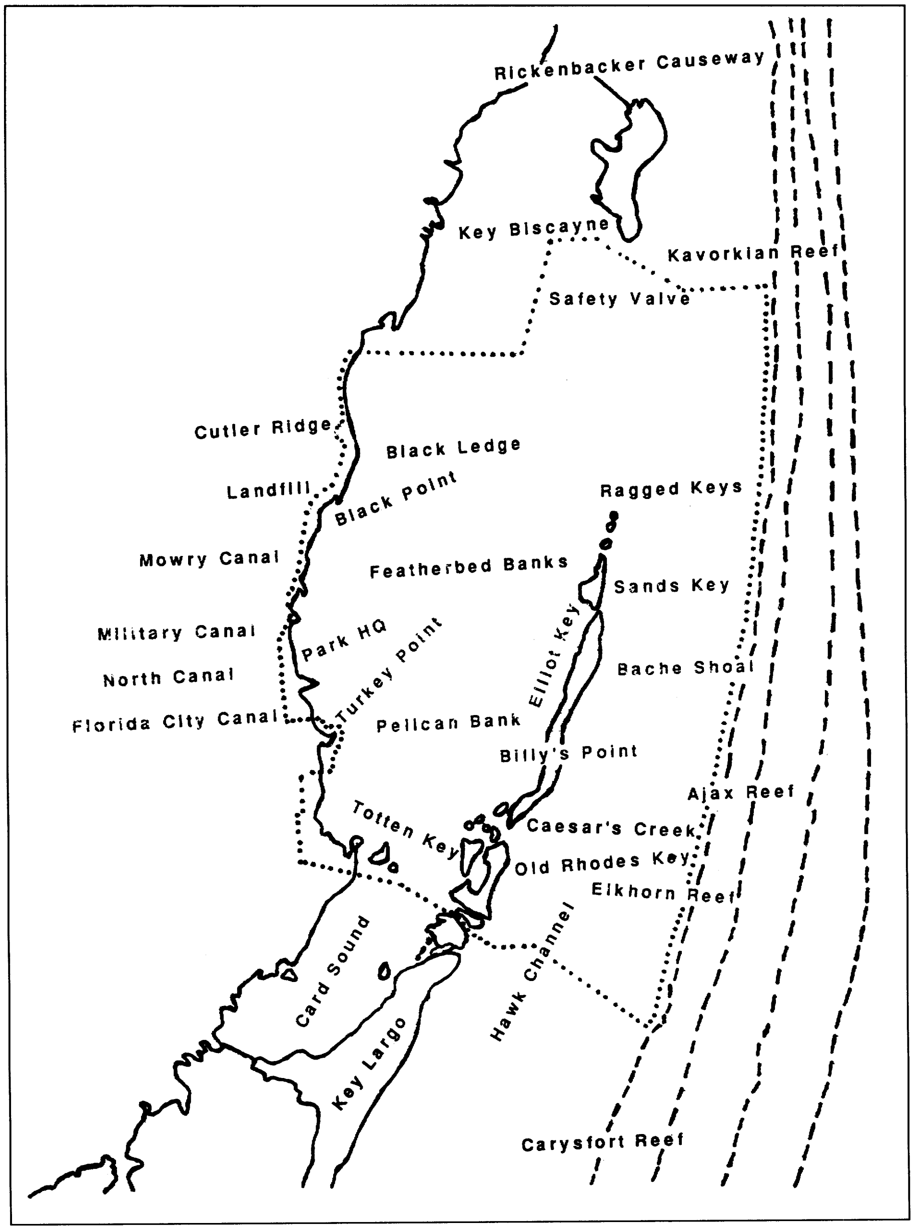


Figure 1. Biscayne National Park (dotted line) and its reefs. Dashed lines are water depths in 50-meter intervals.

Everglades National Park. Within northeast Florida Bay, on the southern edge of the affected area, we measured significant increases in dissolved phosphate and ammonium. Dissolved phosphate is normally less than 4 ppb within this region but was as high as 60 ppb at some stations. In addition, dissolved organic carbon increased from 4 ppm to 40 ppm, suggesting input from an upland source. Increased nutrient loading (carbon, nitrogen, and phosphorus) was also measured along the west coast of Everglades National Park, probably as the result of leaching from the massive amounts of downed vegetation or sediment disturbance.

Sediment movement. The intense winds of the storm moved into the Straits of Florida less than two hours before landfall. As a result, wave development was limited and erosional impacts to the shoreline and

[1]Dade County Department of Environmental Management staff, 1993, personal communication, Miami, FL.

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms

A rolled-over coral head with various sponges and soft corals from a patch reef. Photo: Mark Nicholas.

coastal sea floor were minimal. Brief, but extremely strong, unidirectional currents and onshore tidal surges dominated the shore and marine environments. These effects differed markedly from those during slower-moving south Florida hurricanes (Shinn 1972, Tabb and Jones 1962).

Sand deposition and beach overwash revealed that strong onshore surges occurred along the east coast islands from central Key Biscayne south past Elliott Key, and on the mainland coast of Biscayne Bay, between Rickenbacker Causeway and Turkey Point (Figure 1). On the west coast of Everglades National Park, along-shore transport of sediment occurred between Everglades City and Lostman's River.[2] There was a strong onshore surge at Highland Beach, up the Broad River, and southward to Cape Sable.

All of the beach modifications we observed on both coasts were minor compared with the effects of earlier slower-moving hurricanes, such as Donna in 1960. Lower beach slope erosion from Andrew seldom exceeded 30–100 cm. Lateral erosion of the shoreline was less than 10 m in all areas.

The brief storm surge caused little erosion to the mangrove-dominated coastlines or channel margins. Storm winds and surge uprooted some trees, but mangroves along the channel margins generally survived much better than those further inland. Downed mangroves in a leeward setting commonly lay in the water and remained green at the time of our assessment. These fallen trees have created a rough and unstable shoreline that waves and currents may continue to re-profile. Over time, this process can be expected to release large volumes of organic material into the coastal bays.

In western Biscayne Bay, a tan to brownish sediment layer, up to 50 cm thick, was present within the seagrass beds. This layer was composed of grayish (marl) mud and organic material. We found the more rocky-bottom environments of the eastern side of the bay to have little storm sediment deposition. On the seaward side of the bay, some marl sediments were found in depressions in the stable carbonate banks, but this sedimentation was much less uniform than in the seagrass beds. Although we did not examine the deeper portions of north central Biscayne Bay, we expect that a significant depositional layer also occurred there.

On the offshore reef shelf, deeper blowouts and depressions in the seagrass contained a thick deposit of seagrass blades and other storm-eroded material. However, we found no widespread subtidal storm mud

[2]Place names outside of Biscayne Bay (Figure 1) are given on the map on page 228 this issue.

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms

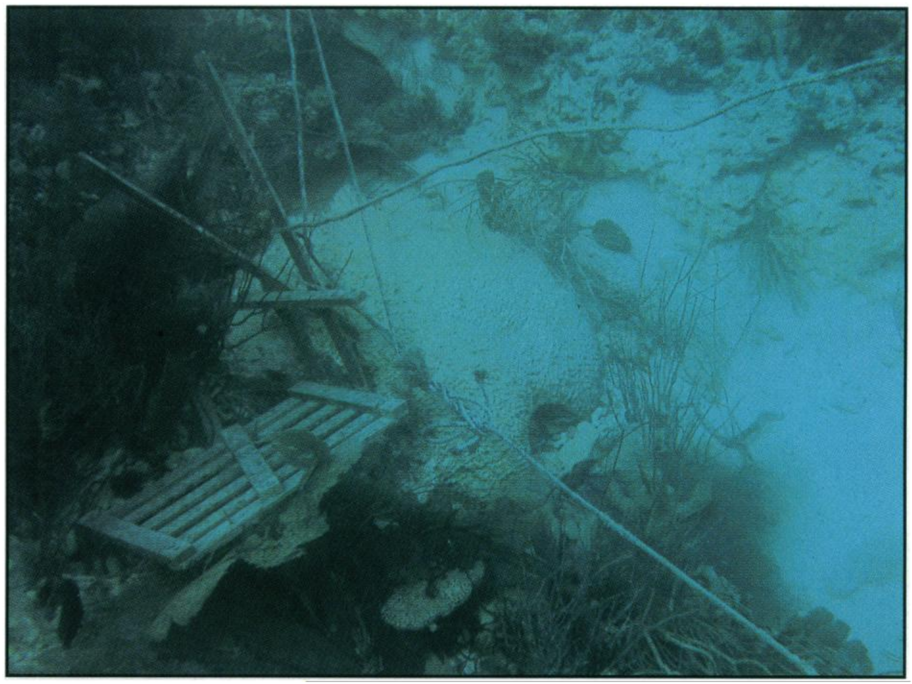
layer. One tidal-ebb sand delta was formed on the eastern side of Elliott Key approximately 3 km from the north end of the island (Figure 1).

On the west coast of Florida, interior bays had a freshly deposited grayish mud layer 20–50 cm thick. A similar gray mud was also found offshore in protected depressions. Traveling by motor boat through the shallow bays, we saw numerous gaseous bubbles rising from the silted bottom. The broad intertidal to shallow subtidal banks sea of Harney River, Broad River, and Lostman's River contained a patchy to widespread layer of sandy mud less than 50 cm thick. We found no significant storm deposits in the channels or on the sea floor further offshore. The storm layer contained some organic material, including mangrove leaves and twigs, but the gray to light gray color (quartz and calcium carbonate material) was surprising in light of the large volumes of dark organic peat and leaf litter that must have been released by the storm.

We found ebb-flow deltas along the west coast at many locations. Probably these deltas formed as waters were receding out of the mangroves and off the beaches. The deltas consisted of a soft, gray mud and ranged from 1 to 3 m thick. Prevailing tidal currents are gradually modifying these deposits, particularly within the channels. Each shore-ebb delta created a seaward lobe or spit of sand and shell extending 10–50 m seaward. The ebb deltas appear to have caused more destruction to the nearshore seagrass beds than waves or currents during the storm.

Seagrass beds. Tropical seagrass beds dominate much of the shallow water coastal environment of South Florida and are known to play an important role in the ecology of the marine ecosystem. Past hurricanes have affected these grassbeds, causing massive loss of leaf material (Thomas et al. 1961, Tabb and Jones 1962). Therefore, an examination of the seagrass beds was an important component of our assessment.

Biscayne National Park. The seagrass communities of Biscayne National Park appeared to be remarkably untouched by the storm.



A dead coral head with part of a commercial lobster trap and associated lines; other debris (sponges and soft corals) is also piled up. Photo: Mark Nicholas.

The difference in the storm's impact onshore and offshore was striking. Ten meters offshore Elliott, Boca Chita, and the Ragged Keys, islands where the terrestrial communities had been essentially leveled, we observed seagrasses, algae, and soft corals in less than 2 m of water that were healthy and untouched. Although water clarity was poor in the deeper portions of central Biscayne Bay, the seagrass beds in that area appeared to have suffered little direct storm damage.

There are numerous areas where storm blowouts were common in the grassbeds before Hurricane Andrew. Most of these areas observed after the storm were unaltered, as evidenced by the presence of attached calcarious algae or gorgonians growing in or adjacent to them. Only the seaward side of the northernmost channel of the Safety Valve area, south of Key Biscayne (Figure 1), had signs of significant erosion. This erosion is in sharp contrast to the effects of Hurricanes Donna (1960), Betsy (1965), and other past storms that have caused extensive destruction to the seagrass bed.

Many people have worried that boat propeller cuts in shallow grassbeds could act as erosional foci during strong storm events. This worry was not validated during Hurricane Andrew. Throughout the tidal banks off the northern Florida Keys, propeller scars seemed unaffected. Underwater observers saw a few centimeters of sediments eroded from the sides and bottom of some cuts, but the rhizophytic algae, including *Halimeda* and *Penicillus*, were still firmly attached.

Seaward of the Keys, we observed only minor modifications to the grassbeds surrounding the reefs. One of the patch-reef areas seaward of northern Elliott Key had a north-south scour channel formed between two reef patches. This channel appeared to be a result of the strong north-to-south current that developed as the hurricane approached. The scour has a pronounced sand delta extending across the adjacent grassbed to the south.

The outer portion of the coastal shelf had slightly greater modifications from the storm. Most characteristic are crescentic lobes of sand deposited on the adjacent seagrasses to the south of many naturally bare areas. These deposits are seen to the south of blowouts in the seagrass beds and south of the bare sand halos around reef patches. We observed these deposits by air as far south as Carysfort Reef. Some pre-

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms

storm blowouts were enlarged toward the shelf margin. Historically, hurricanes have dramatically modified and set back the seagrasses of the outer shelf. This storm appears to have caused fewer modifications than did Betsy in 1965 or Donna in 1960.

Figure 2 presents a post-storm analysis of seagrass plant and blade density at three Dade County long-term monitoring stations. These data indicate that blade density was well within the normal ranges measured before the storm.

Everglades National Park. Florida Bay has undergone dramatic changes in its seagrass beds since 1987, due to an unexplained seagrass dieoff (Robblee et al. 1991). Before Hurricane Andrew, the decay of the stabilizing rhizome mat had left much of the bay vulnerable to erosion. For several months before the storm, bottom sediments had been disturbed and suspended and an area of milky green to brown water had persisted over much of the bay. After Hurricane Andrew, the area appeared unchanged. From air and underwater observations, Florida Bay does not appear to have been affected directly by the storm. However, we expect eventual longer-term alterations to Florida Bay from nutrient increases associated with post-storm runoff.

Along the west coast, the seagrass beds received only minor modification. *Halodule* beds on shallow muddy sand bottom immediately adjacent to Highland Beach were unaffected. The *Thalassia* beds seaward of Broad River and north to Lostman's River also were unaffected, except for small sites where strong north-to-south currents cut linear scours. In most areas, old seagrass blades were still intact, but in some areas the storm had snapped off grass blades and new blades had formed.

Hardbottom communities. As with the other underwater marine resources, hardbottom communities were only moderately affected. In most cases, little change to these resources was discernible with casual visual observations. Typical hardbottom community components, such as the sea plumes (*Plexaura*, *Pterogorgia*, and *Pseudopterogorgia*), calcarious algae (*Halimeda*, *Penicillus*, *Udotea*, and *Rhipocephalus*), and stony corals (*Siderastrea*, *Porites*, and *Manicina*) appeared virtually undisturbed at most locations. We encountered only occasional uprooted sea plumes at some sites.

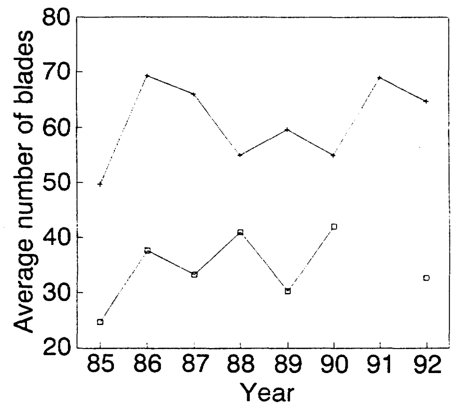


Figure 2. Average number of seagrass blades counted per sampling grid at the Dade County Department of Environmental Resources Management monitoring sites within Biscayne National Park before (top line) and after (bottom line) Hurricane Andrew. Count values shown are an average of three sampling grids at each station as sampled during the fall quarter annually from 1985 to 1992. (Data provided by G. Milano, Dade County Department of Environmental Resources Management.)

Sponges were the most heavily affected component of hardbottom communities. Underwater surveys at a location approximately 1.5 km southwest of Pelican Bank in Biscayne Bay revealed the storm had deposited a fine, flocculent, silty marl sediment, killing and smothering most of the sponges. The only live sponge specimens were loggerhead sponges (*Speciospongia vesparia*). Skeletal remains of dead sponges fell apart readily when handled. The sediment loading did not have a significant impact on stony corals, sea plumes, algae, or seagrasses.

The sponge component of the hardbottom community was also altered near Elliott Key. We located stakes and lines marking a study site established during the summer of 1992 near Billy's Point, and counted all the commercial sponges remaining within the plots. Of the 282 commercial sponges that had been marked and mapped within these plots before the storm, only 140 remained. All sponges, including a variety of sizes, and other organisms present appeared healthy. Change in substrate characteristics consisted of minor sediment loss and scouring. None of the fine flocculent material, so pronounced at stations visited on the western side of the bay, was evident at Billy's Point.

Our observations at Billy's Point revealed that prior data monitoring is crucial. At Billy's Point, casual observation did not reveal any major change from the storm. Only through comparison with earlier counts was the actual extent of impact was discernible.

After our assessment, we received a report of post-hurricane observations at nine juvenile lobster recruitment monitoring stations within southern Biscayne Bay (Butler et al. 1992), none of which we had visited. This report and subsequent discussions with Mark Butler of Old Dominion University in Norfolk, Virginia, revealed severe impacts to the hardbottom communities at two of their monitoring stations. At these stations, sponges, octocorals, and corals were sheared from the substrate and found lying amongst expansive wracks of seagrass, algae, and mangrove leaf debris. Few or no lobsters remain at these stations. The bottom community appeared as though it had been heavily trawled, with as many as 90% of the larger sea whips and sponges missing. The impact was greatest at the southernmost station, on the southern wall of the storm path. Butler and his colleagues reported the loss of nearly all the macroalgae at their western stations. They found less extensive damage in the eastern basin close to Elliott Key.

Hardbottom communities seaward of the keys were relatively undisturbed. Aerial flights and boat transects over several of these areas revealed no evidence of mass destruction or loss of organisms.

Coral reefs. Hurricane Andrew's impact on the south Florida reefs was remarkably limited compared with the impact of other hurricanes. The major damage was detachment and overturning of individual or-

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms

ganisms and breakage of branching species. Abrasion and gouges were also evident on some corals. Damage to soft corals and sponges consisted of detachment, burial, and partial breakage (chunks missing).

We observed no overall mass destruction of whole reefs or reef zones. Damage severity varied greatly within and among reefs, with the most severe damage to corals on Bache Shoals, an inner reef (Figure 1), and to sponges on the deeper offshore reefs. Aerial observations revealed some significant smothering and sandblasting at certain reef locations, but most reefs were relatively undamaged.

Artificial fishing reefs. The Kavorkian Wreck was a 23-meter fishing vessel sunk just seaward of the National Park boundary as an artificial reef in 1984. The vessel was originally placed in 21 m of water and had shown little deterioration before the storm. It was located about 70 m from a healthy natural reef.

Hurricane Andrew completely destroyed this vessel and threw it against the nearby natural reef located within the Park. The wreck was almost completely turned inside out, and the wreckage was reshaped to conform to the shape of the reef. After the storm, the vessel protruded less than 1.5 m above the sea bottom, compared to its original 5-meter profile. Our survey of the natural reef at this location revealed little evident damage to the rock substrate or its sparse reef organisms. Sediment around the site was a fine, easily disturbed marl, but there was little deposition of this material on the wreck itself or in the numerous depressions on the reef. At the time of the survey, there was a noticeable current, sufficient to scour the reef and wreck.

Marine fish. South Florida is world renowned for its saltwater fishing and tropical reef fish viewing opportunities. Marine fish constitute an important economic, aesthetic, and ecological component of the marine ecosystem. Past hurricanes have resulted in mass mortality within Florida's coastal fish populations (Robins 1957, Thomas et al. 1961, Tabb and Jones 1962), but we found the impacts of Hurricane Andrew to be minimal.

Biscayne National Park. Fish populations appeared healthy in all the locations we investigated. During a 30-minute dive off Ajax Reef (Figure 1) in 21 m of water, we recorded 22 species, and population numbers appeared normal. Fish counts conducted at this location by J. Tilmant and G. P. Schmahl in the early 1980s averaged between 20 and 28 species per 30 minutes of observation. Along the outer reef edge near the northern boundary of the park, more than 15 species were encountered during a 16-minute dive in conditions of relatively low visibility. During investigations on several patch reefs in 6–9 m of water, the reef fish appeared undisturbed. Only a few individuals were seen with tattered fins or body scrapes suggesting any battering about by heavy wave surge.

At Elkhorn Reef, where there was relatively heavy coral damage on the upper reef surface, fish typically were still present in large numbers. The loss of much of the *Acropora palmata* coral forest on the reef top resulted in an unusual open aggregation of glassy sweepers (*Pempheris schomburgki*), Spanish grunts (*Haemulon macrostomum*), and other species usually found in more protective habitat. These species were displaced from their normal habitat and may not have yet located new areas of suitable cover.

Several fish that had been tagged before the storm within the area of Caesar's Creek (Figure 1) by researchers from the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences were observed after the storm within the same area.[3] We also observed a typical abundance of small snappers (*Lutjanus* spp.) and grunts (*Haemulon* spp.) within the mangrove creeks and prop-root systems, suggesting that the juvenile fish occurring within these habitats were little affected. Based on our observations and the reports received, it appears that, although some individual fish suffered minor body damage, losses of tropical reef species were not significant.

The staff of Biscayne National Park has received several reports of excellent sport fishing since the storm.[4] Bay shrimpers who had returned to trawling reported catches greatly exceeding those typically found this time of year. Other incidental observations also suggest that fish were relatively abundant after the storm. In seagrass beds near the Featherbed Banks, a large number of juvenile snappers were observed, and in hardbottom areas east of Black Ledge near in the middle of Biscayne Bay several schools (numbering 15–30 individuals) of pinfish (*Lagodon rhomboides*) were encountered.

Everglades National Park. During the first several weeks after the storm, the park and the Florida Department of Natural Resources Marine Research Institute (FDNR/MRI) received several reports of massive fish kills within the mangrove zone of Everglades National Park. They also received several reports of an extremely strong smell of hydrogen sulfide over the entire west coast region. These factors suggest that a significant amount of mortality occurred either during the storm or in relation to depleted oxygen levels associated with organic loading immediately afterward. During our investigations of the west coast area, four weeks after the storm, we encountered no evidence of fish kills.

FDNR/MRI sent a team from Everglades City on 3 September 1992 to measure water quality conditions and the extent of fish kills. The team did not encounter any dead fish during their survey, although they were unable to get into the upper (more inland) mangrove areas. They reported local fisherman had seen dead mullet (*Mugil* spp.), catfish (*Arius* and *Bagre* spp.), snook (*Centropomus undecimalis*), mangrove snapper (*Lutjanus griseus*), sand perch (*Diplectrum formosum*), pinfish, and blue crab (*Callinectes sapidus*) around the Barron River. The team observed many mollusks,

[3]Michael Schmale, 1993, personal communication. Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, FL.

[4]R. Curry, 1993, personal communication. Biscayne National Park, Biscayne, FL.

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms

mostly quahog (*Mercenaria mercenaria*), horse conch (*Pleuroploca gigantea*), and horseshoe crab washed up on shore at Pavilion Key.[5]

Like Biscayne National Park, the Everglades has received numerous reports of good sportfishing along the park's west coast since the storm.[6] Fishermen report good catches of snook, redfish, seatrout, and tarpon. Researchers investigating the mangrove areas also reported frequently seeing feeding tarpon.

Marine wildlife. Nonfish marine vertebrate species are an important component of the south Florida ecosystem. Many of these species are considered threatened or endangered by the US Fish and Wildlife Service. Our assessment included three species: sea turtles, manatees, and crocodiles.

Sea turtles. Before Hurricane Andrew, the more than 57 km of beaches in Everglades National Park provided abundant nesting habitat for loggerhead sea turtles (*Caretta caretta*). The Cape Sable region provided the largest nesting rookery in the park, with additional nesting occurring on Highland Beach and on the spits and crescent beaches of numerous islands west and south of Everglades City. Since the early 1970s, annual estimates ranged from 817 to 1644 nests.[7]

Hurricane Andrew hit in the middle of the turtle hatching. Based on nesting frequencies from past studies and monitoring efforts of the last three years, eggs in an estimated 40–50% of the Cape Sable nests and in approximately 25% of the nests in the Everglades City area should have hatched before the storm. We estimate that approximately 50–60% of the nests remaining to hatch after 24 August would fail, due to a compacted overburden of sediment or exposure from erosion. Sea turtles are long-lived animals, and in regard to long-term productivity this event is not likely to be significant. Overall, the impact of Hurricane Andrew on sea turtle nesting habitat in south Florida was minimal and, due to sand deposition, it may have resulted in improvement at some locations.

Manatees. Manatees (*Trichechus manatus latirostris*) are commonly observed in both Everglades and Biscayne National Parks. However, there is a marked spatial and temporal pattern to their distribution. Since March 1990, Everglades National Park staff have performed a monthly aerial survey of manatees, and the data permit a post-hurricane evaluation. Post-storm aerial surveys followed the same methods as the earlier monthly surveys, covering the entire mangrove coastline from Card Sound Road to the Everglades park boundary north of Everglades City.

One-hundred five groups of manatees, totaling 209 individuals, were observed during 7.37 survey hours. This count is the highest since the Everglades study began (Snow 1992). The highest previous count was 181 individuals in August 1991. The monthly average for the year preceeding Hurricane Andrew (March 1991 to February 1992) is 120.9 manatees.

During the survey year preceeding Andrew, the percentage of calves observed per month varied from 6.4% to 14.0%. In the post-storm survey, calves comprised 9.6% of the individuals, and they appeared to have survived the storm well. During that survey, approximately 10% of the manatees observed were in northern Florida Bay between Cape Sable and the Card Sound Road. The number observed is more than twice the number of manatees expected in that area. No dead manatees were observed, and no immediate post-hurricane mortality was reported to the Florida Department of Natural Resources.

Crocodiles. Most crocodiles (*Crocodylus acutus*) and all of the known crocodile nesting in Everglades National Park is in northern Florida Bay between Long Sound and Cape Sable. A fixed-wing aircraft survey of the crocodile habitat covered the entire coastal mangrove fringe from Long Sound to Everglades City on 18 September. A boat surveyed the core crocodile nesting habitat in northeastern Florida Bay. These surveys found little damage to inhabited areas or nesting beaches and, importantly, observed no erosion damage to known nest sites.

Recommended future studies

The underwater marine resources of south Florida did not suffer the level of direct physical perturbation normally associated with strong hurricanes. The rapid forward speed with which this hurricane approached and then crossed the peninsula of Florida is probably the primary reason stronger underwater forces did not develop. The impact was moderate at the community-ecology level, and the system should be able to readily recover through normal regenerative processes.

There are some exceptions to this general conclusion, for example the submerged resources of some hard-bottom communities of central Biscayne Bay. There, the loss of sponges, coral, and algae may have resulted in an immediate, long-term impact on the juvenile spiny lobster (*Panulirus argus*) population. During their early postlarval life, lobsters rely on cover provided by sponges and coral (Butler et. al. 1992). Continued on-site monitoring and evaluation of the future lobster fisheries harvest will be extremely important to evaluate the overall extent of the impact.

In addition, the 1992–1993 winter storms may play a key role in the resuspension and distribution of sediments. The sedimentation loading apparent throughout much of Biscayne Bay may result in future loss of many marine organisms, particularly sponges. It will be important to continue to monitor the bay to document the overall community response to the sediment layer.

A perplexing unresolved question concerns the damage to deeper reefs off Biscayne National Park and the movement of the artificial reef in more than 20 m of water. Relatively strong currents must have been responsible, yet evidence of such currents is not apparent over the shallow reef platform. The exact nature and location of strong currents associated with the storm needs to be

---

[5]Pete Nabor and Sharon Tyson, 1993, personal communication, Florida Department of Natural Resources, Marine Research Institute.

[6]E. Thue, 1993, personal communication. Everglades National Park, FL.

[7]R. W. Snow, 1993, personal communication.

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms

further reconstructed through field investigations and analysis by physical oceanographers.

The great impact on mangrove and upland forest communities contrasted sharply with the small impact underwater. It was remarkable to snorkel in water a few meters from shore and observe a seagrass bed virtually undisturbed when the adjacent shoreline forest appeared devastated. The overall impact to the mangrove forest within Biscayne and Everglades National Park exceeds that recorded for any other hurricane within this region (see figure page 261 this issue).

A critical question is whether the ecosystem of south Florida can still respond naturally to a perturbation like Hurricane Andrew. There has been considerable recent biological evidence that the marine resources of this region may be under high levels of stress from ecosystem alterations, low but chronic levels of pollution, and the direct physical impact of boating and recreational activities (Braman et al. 1989, Davis 1977, Dustan 1977, Glynn et al 1989, Lessios et al. 1984). Historically, hurricanes are a part of the environmental forces of the region. Plant and animal communities have evolved under their influence. Their evolution, however, has not included the anthropogenic stress to which the system is now subjected.

Although the hurricanes's direct physical impact to the marine resources was not extensive, post-hurricane anthropogenic stress may be severe. We must carefully monitor and evaluate the ability of the marine ecosystem to incorporate and overcome the massive increases in turbidity, large concentrated releases of nutrients, and extensive destabilization of sediments that is occurring and is expected to continue. In most cases, the storm radically altered the natural overland flow from upland marshes into marine areas.

The most challenging question for future study is: Has Hurricane Andrew, coupled with human alterations, provided a perturbation that will cause a permanent change in former successional processes and result in a new form of ecosystem stability for the region?

Acknowledgments

Numerous people contributed information and assistance during our assessment, and it would not be possible to name them all. However, the following persons provided data or conducted parts of the survey: Rick Alleman, Doug Haymans, Walter Jaap, Jan Landsberg, Brian Lockwood, Frank J. Mazzotti, Gary Milano, Mitch Murray, Mark Nicholas, Jim Porter, Rebecca Rutledge, Chris Sinigalliano, and Cecelia Weaver.

References cited

Braman, R. S., D. F. Martin, and R. N. Strom. 1989. Environmental contamination of coral reef areas. Final Project Report to the Florida Marine Research Institute, Florida Department of Natural Resources, St. Petersburg, FL.

Butler, M. J., W. F. Herrnkind, and J. H. Hunt. 1992. A preliminary assessment of hurricane Andrew's impact on hard-bottom community structure and spiny lobster populations in Biscayne Bay and a prospectus for a long-term monitoring and experimental recovery study. Department of Biological Sciences, Old Dominion University, Norfolk, VA.

Connell, J. H. 1978. Diversity in tropical rain forests and coral reefs. *Science* 199: 1302–1310.

Davis, G. E. 1977. Anchor damage to a coral reef on the coast of Florida. *Biol. Conserv.* 11: 29–34.

Dustan, P. 1977. Besieged reefs of Florida's Keys. *Nat. Hist.* 86: 73–76.

Glynn, P. W., A. M. Szmant, E. F. Corcoran, and S. V. Cofer-Shabica. 1989. Condition of coral reef Cnidarians from Biscayne National Park reef tract: pesticides, heavy metals and histopathological examination. National Park Service, Southeast Region Research/Resources Management Report SER-89/03, Atlanta, GA.

Lessios, H. A., D. R. Robertson, and J. D. Cubit. 1984. Spread of *Diadema* mass mortality through the Caribbean. *Science* 226: 335–337.

Pearson, R. G. 1981. Recovery and recolonization of coral reefs. *Mar. Ecol. Prog. Ser.* 4: 105–122.

Porter, J. W., J. D. Woodley, G. J. Smith, J. E. Neigel, J. F. Battey, and D. G. Dallmeyer. 1981. Population trends among Jamaican reef corals. *Nature* 294: 249–250.

Robblee, M. B., T. R. Barber, P. R. Carlson, M. J. Durako, J. W. Fourqurean, L. K. Muehlstein, D. Porter, L. A. Yarbro, R. T. Zieman, and J. C. Zieman. 1991. Mass mortality of the tropical seagrass *Thalassia testudinum* in Florida Bay (USA). *Mar. Ecol. Prog. Ser.* 71: 297–299.

Robins, C. R. 1957. Effects of storms on the shallow-water fish fauna of southern Florida with new records of fishes from Florida. *Bull. Mar. Sci.* 7: 226–275.

Shinn, E. A. 1972. Coral reef recovery in Florida and in the Persian Gulf. Environmental Conservation Department, Shell Oil Co., Houston, TX.

Smith, T. J. III, M. B. Robblee, H. Wanless, and T. W. Doyle. 1994. Mangroves, hurricanes, and lightning strikes. *BioScience* 44: 256–262.

Snow, R. W. 1992. The distribution and relative abundance of the Florida manatee in Everglades National Park: an interim report of aerial survey data from March 1991 through February 1992. South Florida Research Center, Everglades National Park.

Stoddart, D. R. 1963. Effects of Hurricane Hattie on the British Honduras reefs and cays, October 30–31, 1961. *Atoll Res. Bull.* 95: 1–142.

Tabb, D. C., and A. C. Jones. 1962. Effect of Hurricane Donna on the aquatic fauna of north Florida Bay. *Trans. Am. Fish. Soc.* 91: 375–378.

Thomas, L. P., D. R. Moore, and R. C. Work. 1961. Effects of hurricane Donna on the turtle grass beds of Biscayne Bay, Florida. *Bull. Mar. Sci.* 11: 191–197.

This content downloaded from 165.83.133.250 on Wed, 20 Sep 2017 17:07:53 UTC
All use subject to http://about.jstor.org/terms